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ISO 4706

Third edition
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Gas cylinders — Refillable welded steel cylinders — Test pressure 60 bar and below

Bouteilles à gaz — Bouteilles en acier soudées rechargeables — Pression d'essai de 60 bar et moins

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 58, *Gas cylinders*, Subcommittee SC 3, *Cylinder design*.

This third edition cancels and replaces the second edition (ISO 4706:2008), which has been technically revised.

The main changes are as follows:

— references have been updated;

— X-ray is required on three-piece designs;

— X-ray frequency has been changed from 50 to 250;

— criteria for X-ray retesting requirements have been added.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to facilitate agreement on the design and manufacture of welded-steel gas cylinders in all countries. The requirements are based on knowledge of, and experience with, materials, design requirements, manufacturing processes and controls in common use for the manufacture of gas cylinders.

This document has been prepared to address the general requirements in chapter 6.2 of the UN model regulations for the transportation of dangerous goods ST/SG/AC.10/1 Rev. 22.[1]

Gas cylinders — Refillable welded steel cylinders — Test pressure 60 bar and below

1 Scope

This document specifies the minimum requirements concerning material selection, design, construction and workmanship, procedure, and test at manufacture of refillable welded-steel gas cylinders of water capacities from 0,5 l up to and including 150 l and drums of water capacities of 150 l to 500 l of a test pressure not greater than 60 bar[1)], exposed to extreme worldwide temperatures (–50 °C to +65 °C) used for compressed, liquefied or dissolved gases.

NOTE Unless specified in the text, for the purpose of this document, the word "cylinder" includes "pressure drums".

This document is primarily intended to be used for industrial gases other than liquefied petroleum gas (LPG), and is also applicable to LPG.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4136, *Destructive tests on welds in metallic materials — Transverse tensile test*

ISO 5817, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

ISO 7438, *Metallic materials — Bend test*

ISO 9606-1, *Qualification testing of welders — Fusion welding — Part 1: Steels*

ISO 10286, *Gas cylinders — Vocabulary*

ISO 11117, *Gas cylinders — Valve protection caps and guards — Design, construction and tests*

ISO 11363-1, *Gas cylinders — 17E and 25E taper threads for connection of valves to gas cylinders — Part 1: Specifications*

ISO 15613, *Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test*

ISO 15614-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

ISO 14732, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*

ISO 17636-1, *Non-destructive testing of welds — Radiographic testing — Part 1: X- and gamma-ray techniques with film*

ISO 17636-2, *Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors*

1) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

ISO 17637, *Non-destructive testing of welds — Visual testing of fusion-welded joints*

ISO 17639, *Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions in ISO 10286 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
yield strength
value corresponding to the upper yield strength, R_{eg}, or, for steels when yielding does not occur at tensile testing, the 0,2 % proof strength (non-proportional elongation), $R_{p0,2}$

3.1.2
normalizing
heat treatment in which a cylinder is heated to a uniform temperature above the upper critical point (Ac3) of the steel to regenerate or homogenize the metallurgical structure of the steel, to a sufficient degree to achieve the desired mechanical properties, and then cooled in a controlled or still air atmosphere

3.1.3
stress relieving
heat treatment given to the cylinder, the object of which is to reduce the residual stresses without altering the metallurgical structure of the steel, by heating it to a uniform temperature below the lower critical point (Ac1) of the steel, then cooling it in a controlled or still air atmosphere

3.1.4
stabilizing
heat treatment given to the cylinder, the object of which is to stabilize the structure of the steel by heating it to a uniform temperature above the lower critical point (Ac1) of the steel and subsequently cooling it to obtain the desired mechanical properties.

3.1.5
batch
quantity of cylinders made consecutively by the same manufacturer using the same manufacturing techniques, to the same design, size and material specifications using the same type of welding machines, welding procedures and to the same heat treatment conditions

Note 1 to entry: In this context, "consecutively" need not apply to continuous production (start to finish).

Note 2 to entry: See 12.1 for specific batch quantities.

3.1.6
base materials
steel used to manufacture the cylinder including the pressure and non-pressure-retaining materials of construction

3.1.7
cylinder shell
cylinder after completion of all forming, welding and heat treatment operations

3.1.8
F factor (*F*)
design stress factor

3.1.9
parent material
pressure-retaining materials used in the fabrication of the cylinder

3.1.10
overlap
placement of steel on top of or below a weld joint for the purpose of joint alignment or added joint strength

3.1.11
embossed
carve, mould or stamp a design on a surface or object so that it stands out in relief

3.2 Symbols

Symbol	Definition	Unit
a	calculated minimum thickness of the cylindrical shell	mm
a_1	calculated minimum value of a used in the calculation of b (see 7.2.2) of the cylinder head	mm
A	minimum elongation after fracture	%
b	calculated minimum thickness of the end	mm
C	shape factor	—
D	outside diameter of the cylinder as given in the design drawing	mm
D_p	mandrel diameter	mm
e	thickness of metal which is offset (see Figure 4)	mm
e_1	thickness of metal which is not offset (see Figure 4)	mm
h	height of the cylindrical part of the end	mm
H	outside height of the domed part of the end	mm
J	stress reduction factor	—
K	ellipsoidal ratio	—
L	length of the cylinder	mm
L_0	original gauge length in accordance with ISO 6892-1	mm
n	ratio of diameter of bend test former to the thickness of the test piece	—
N	normalized cylinder	—
P_b	highest pressure reached in the cylinder during the burst test (see ISO 10286)	bar
P_h	actual test pressure applied to the cylinder by the manufacturer	bar
r	inside knuckle radius of the end	mm

R	inside dishing radius of the end	mm
R_e	actual value of yield strength determined by tensile test specified in 9.1.2.2.1.2	MPa
R_{eg}	minimum value of yield strength guaranteed by the cylinder manufacturer for the finished cylinder	MPa
R_m	actual value of tensile strength determined by the tensile test specified in 9.1.2.2.1.2	MPa
R_{mg}	minimum value of tensile strength guaranteed by the cylinder manufacturer for the finished cylinder	MPa
$R_{po,2}$	0,2 % proof strength (see ISO 6892-1)	MPa
S_0	original cross-sectional area of tensile test piece in accordance with ISO 6892-1	mm^2

4 Inspection and testing

To ensure that the cylinders conform to this document, they shall be subject to inspection and testing in accordance with Clauses 7, 8, 9 and 10.

Tests and examinations performed to demonstrate conformity to this document shall be conducted using instruments calibrated before being put into service and thereafter according to an established programme.

5 Materials

5.1 General

5.1.1 The material used for the fabrication of the gas cylinder shall be steel, other than rimming quality, suitable for pressing or drawing and welding, and shall not deteriorate with time (i.e. non-ageing). The steel grades used shall have specified, guaranteed, mechanical properties that are possible to achieve for the finished cylinder after normalizing, stress relieving or stabilizing.

In cases where verification of the non-ageing property of the material is required, the criteria by which it is to be specified should be agreed by the manufacturer and purchaser and included in the order.

5.1.2 Materials for shells and end pressings, excluding bosses (see 5.1.3), shall conform to the requirements of 5.1.8 and 5.2.1.

5.1.3 Bosses shall be manufactured from compatible weldable materials with a maximum carbon content of mass fraction of 0,25 %.

5.1.4 All items welded to the cylinder (e.g. shrouds and footrings) shall be made of compatible weldable material containing the maximum values in % (mass fraction) given in Table 3.

5.1.5 The welding consumables shall be such that they are capable of giving consistent welds with a minimum tensile strength at least equal to that specified for the parent materials in the finished cylinder.

5.1.6 The cylinder manufacturer shall have certificates of the ladle analysis and mechanical properties of the steel supplied for the construction of the pressure-retaining parts of the cylinder. The cylinder manufacturer shall also have certificates of the ladle analysis for items welded to the cylinder (e.g. shrouds and footrings).

5.1.7 A system of identification shall be in place to determine the cast(s) of steel used for the construction of the pressure-retaining parts of the cylinder.

5.1.8 Grades of steel used for cylinder manufacture shall be compatible with the intended gas service (e.g. corrosive or embrittling gases).

5.2 Chemical composition

5.2.1 Materials used for the fabrication of gas cylinders shells and end pressings shall be of weldable quality and contain the values in % (mass fraction) given in Table 1.

Table 1 — Cylinder shell and ends chemistry allowable limits

Element	Maximum content % (mass fraction)
Carbon	0,250
Silicon	0,450
Manganese	1,600
Phosphorus	0,040
Sulfur	0,040

The use of micro-alloying elements such as niobium, titanium and vanadium shall not exceed the values given in Table 2.

Table 2 — Micro alloying chemistry allowable limits

Element	Maximum content % (mass fraction)
Niobium	0,05
Titanium	0,03
Vanadium	0,10
Niobium plus Vanadium	0,12

Table 3 — Attachments welded to the cylinder chemistry allowable limits

Element	Maximum content % (mass fraction)
Carbon	0,250
Phosphorus	0,040
Sulfur	0,040

Where other micro-alloying elements are used, their presence and amounts shall be reported, together with those already described in 5.2.1, in the steel manufacturer's certificate.

5.2.2 In any check analysis, the maximum permissible deviation from the limits specified for the cast analyses shall conform to the values in 5.2.1.

6 Design

6.1 General requirements

6.1.1 The calculation of the wall thickness of the pressure parts to resist the internal pressure in the gas cylinders is related to the yield strength of the material for the finished cylinder.

6.1.2 For calculation purposes, the value of the yield strength, i.e. R_{eg}, is limited to a maximum value of:

a) 0,75 R_{mg} for finished cylinders with a guaranteed tensile strength (R_{mg}) < 490 MPa;

b) 0,85 R_{mg} for finished cylinders with a guaranteed tensile strength (R_{mg}) ≥ 490 MPa.

6.1.3 The internal pressure, on which the wall thickness calculation of the gas cylinder is based, shall be the minimum test pressure, P_h.

6.1.4 A fully dimensioned drawing including the specification of the material shall be produced.

6.2 Valve protection

The design of the cylinder shall provide protection for valves against damage in order to avoid release of contents. When the requirements of 8.6 are not met, then the cylinders shall be conveyed in crates or cradles or shall be provided during transportation with some other effective valve protection, unless it can be demonstrated that the valve can withstand damage without leakage of product.

6.3 Design of openings

6.3.1 The location of all openings shall be restricted to the ends of the cylinder.

6.3.2 Each opening in the cylinder shall be reinforced, either by a valve boss or pad, of weldable and compatible steel, securely attached by welding and so designed as to be of adequate strength and to result in no harmful stress concentrations. Conformity shall be confirmed by calculation or performing a fatigue test in accordance with the requirements of 11.3.

6.3.3 The welds of the openings shall be separated from circumferential and longitudinal joints by a distance not less than 3a.

6.3.4 Particular care shall be taken to ensure that neck threads are accurately cut, are of full form and are free from any sharp profiles, e.g. burrs (see ISO 11363-1).

6.3.5 If the leak-tightness between the valve and the cylinder is assured by a metallic seal (e.g. copper), a suitable internal valve boss can be fitted to the cylinder by a method that need not independently assure leak-tightness.

7 Calculation of minimum wall thickness (sidewall and ends)

7.1 Sidewall thickness

The guaranteed minimum sidewall thickness of the cylindrical shell, a, shall not be less than the thickness calculated using Formula (1):

$$a = \frac{D}{2}\left(1 - \sqrt{\frac{10\,JF\,R_{eg} - \sqrt{3}\,Ph}{10\,JF\,R_{eg}}}\right) \quad (1)$$

where

the value of F is the lesser of:

$$\frac{0{,}65}{R_{eg} / R_{mg}} \text{ or } 0{,}85$$

and for longitudinal welds:

J 1,0 for completely radiographed seams;

J 0,9 for spot-radiographed seams;

J 1,0 for cylinders without a longitudinal weld.

The value of J shall be selected in accordance with 9.4.

Formula (1) is not applicable where the length of the cylindrical portion of the cylinder, measured between the beginning of the domed parts of the two ends, is not more than $\sqrt{2bD}$. In this case, the wall thickness shall be not less than that of the domed part (see 7.2.2).

The sidewall thickness shall also satisfy the following:

— for $D \leq 100$ mm: $a = 1{,}1$ mm;

— for $D > 100$ and $D \leq 150$ mm: $a = 1{,}1 + 0{,}008(D - 100)$ mm;

— for $D > 150$ mm: $a = (D/250) + 0{,}7$ mm (with an absolute minimum of 2,0 mm);

For acetylene cylinders with $D > 300$ mm, the minimum wall thickness shall be 3,0 mm.

The burst pressure ratio shall be demonstrated as follows:

— $P_b \geq P_h \times 2$ and ≥ 50 bar.

7.2 Design of ends concave to pressure

7.2.1 Unless otherwise specified in 6.3, the shape of ends of gas cylinders shall be such that:

a) for torispherical ends $R \leq D$; $r \geq 0{,}1\ D$; $h \geq 4b$ [see Figure 1 a)];

b) for semi-ellipsoidal ends $H \geq 0{,}192\ D$; $h \geq 4b$ [see Figure 1 b)].

7.2.2 The head thickness of all other end shapes shall be not less than that calculated using Formula (2).

$$b = a_1 C \tag{2}$$

where

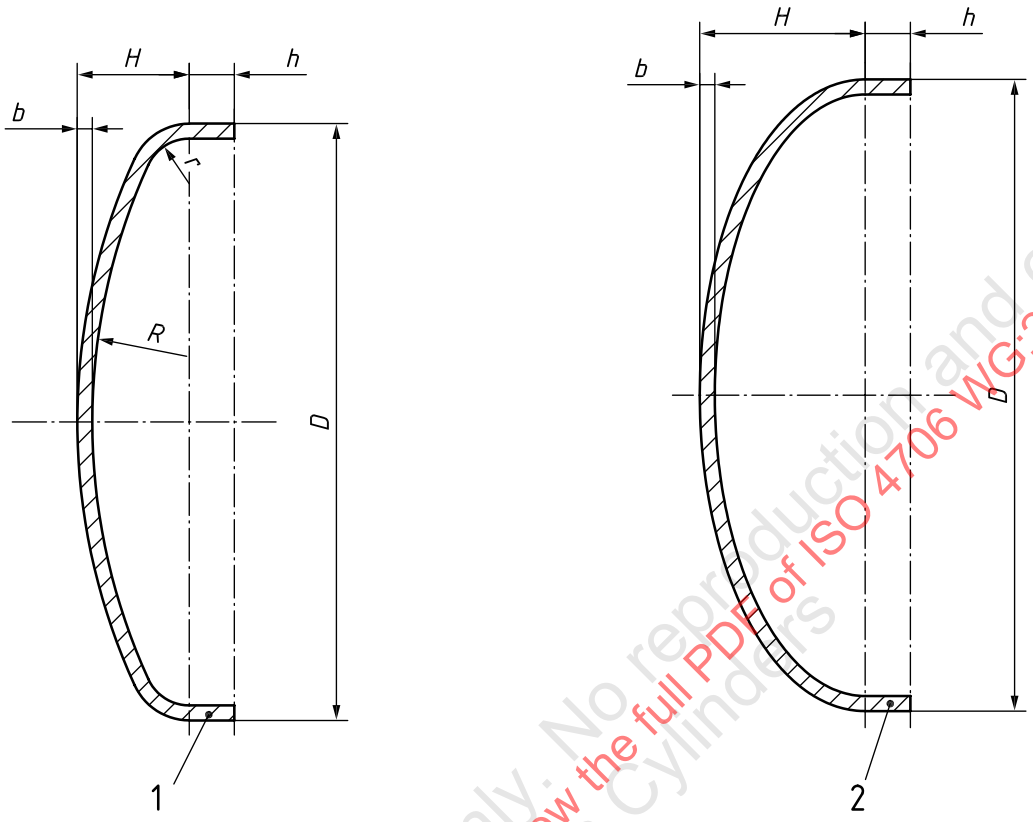
a_1 is the value of a calculated in accordance with 7.1 using $J = 1{,}0$;

C is a shape factor, the value of which depends on the ratio H/D, and shall be obtained from the graph shown in Figure 2 or Figure 3, as applicable.

7.2.3 Heads that do not contain markings may be 90 % of the minimum sidewall thickness as indicated in 7.1.

Ends shaped other than those specified in 7.2 may be used provided that the adequacy of their design is demonstrated by fatigue testing in accordance with the requirements of 11.3.

For heads convex to pressure, the minimum head thickness shall be a minimum of two times that specified in 7.2.2.



a) Torispherical end **b) Semi-ellipsoidal end**

Key

1 torispherical end

2 semi-ellipsoidal end

a) for torispherical ends:

$$H=(R+b)-\sqrt{\left[(R+b)-\frac{D}{2}\right]\times\left[(R+b)+\frac{D}{2}-2(r+b)\right]}$$

b) for semi-ellipsoidal ends:

$$H=\frac{(D+2)(K)(b-2)(b)}{2(K)}\text{ with }K=\frac{\left(\frac{D}{2-b}\right)}{\left(\frac{H}{b}\right)}$$

Figure 1 — Illustration of cylinder ends concave to pressure

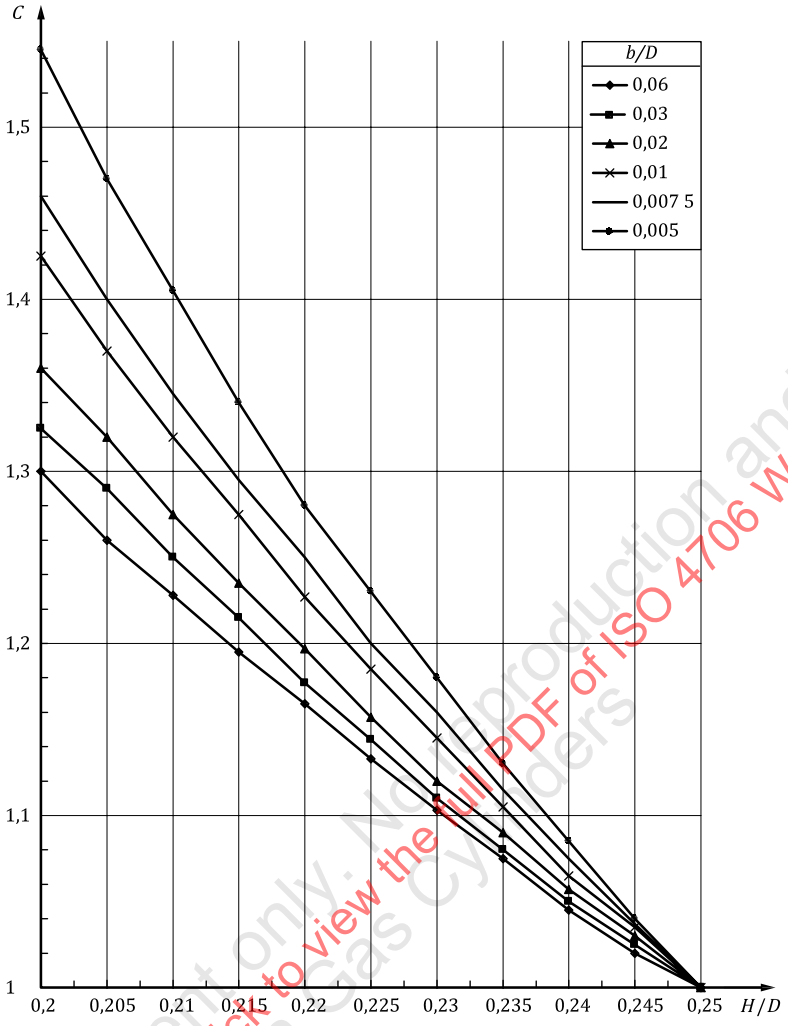


Figure 2 — Values of shape factor C for H/D between 0,2 and 0,25

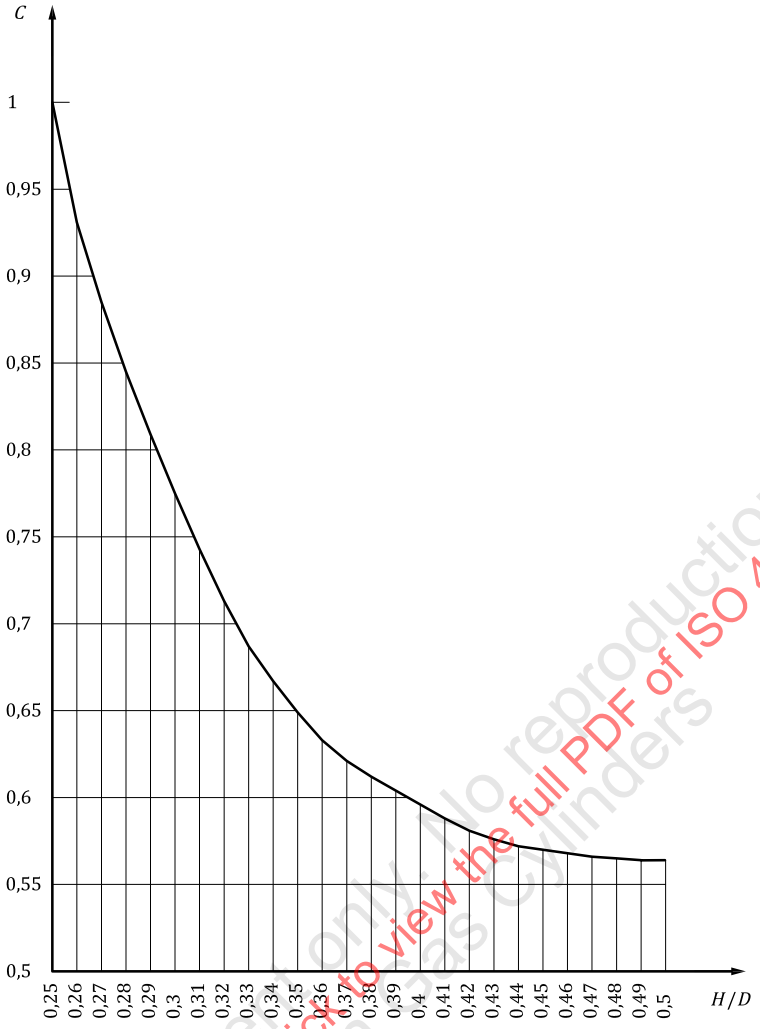


Figure 3 — Values of shape factor C for H/D between 0,25 and 0,5

8 Construction and workmanship

8.1 Welding qualification

8.1.1 General

The following requirements apply:

a) before proceeding with the production of a given design, all welding operators and welding procedures shall be approved by meeting the requirements of 8.1.2 to 8.1.9, ISO 9606-1, ISO 15613, ISO 15614-1 Level 1 or ISO 14732;

b) records of both qualifications shall be kept on file by the manufacturer;

c) weld approval tests shall be made in such a manner that the welds shall be representative of those made in production;

d) welders shall have passed the approval tests for the specific type of work and procedure specification concerned.

8.1.2 Base materials (pressure and non-pressure)

Base materials defined in the procedure specification shall be of the same specification as the given design and those tested by the welders.

8.1.3 Positions of welds

For welder qualification, the position of the part for welding shall be as specified in 8.1.1 c).

8.1.4 Welding materials

Weld consumables (see 5.1.5) shall be the same specification as those specified in the procedure specification, those tested by the welders and those used for production.

8.1.5 Retesting

Where a welder fails to meet the requirements of a weld test:

a) an immediate retest may be made of two test welds of the type that failed, both of which shall meet all the test requirements; or

b) a retest may be made provided there is evidence that the operator has had further training and practice in the design and procedure specification.

8.1.6 Period of effectiveness

The following requirements apply:

a) a welder shall be re-qualified if the design has not been produced by the welder for a period of three months or more;

b) records of welder effectiveness shall be retained by the manufacturer.

8.1.7 Changes to welding process requiring recertification

The procedure specification and welder qualification shall be set-up and tested when there is:

a) a change to the base materials used;

b) a change to the welding material used;

c) a change to the weld process;

d) a change to the weld position;

e) a decrease of 30 °C or more in the minimum specified preheating temperature;

f) a change from one heat treatment process to another (normalizing, stress relieving, stabilizing);

g) the omission or addition of a backing strip in single pass welds;

h) a change from multiple pass to single pass per side;

i) a change from a single arc to multi arc, or vice versa;

j) a change to the shielding gas or to the composition of the shielding gas (if there is a change greater than 15 % in the mixture).

8.1.8 Welder qualification tests

When required, the weldment shall, after radiography:

a) for longitudinal welds, pass:

   1) a bend test of the weld root;

   2) a weld tensile test;

b) for circumferential welds, pass:

   1) a bend test of the weld root;

   2) a weld tensile test;

c) for threaded connections to heads or bottoms, pass macro tests, 180° apart;

d) for welded attachments, foot rings, collars or lugs, pass a macro test;

e) for fillet welds used for the attachment of bottom heads [see Figure 4 b)], pass macro tests, 180° apart.

8.1.9 Results of welder qualification

The following requirements apply:

a) for radiography: as specified in 9.4.1;

b) for bend tests: upon completion of the test, the test piece (weld metal and parent material) shall remain uncracked;

c) for tensile tests: the tensile strength (R_m) value obtained shall not be less than that guaranteed by the cylinder manufacturer (R_{mg}) regardless of the fracture location;

d) for macro tests: the etched specimen shall be visually examined to determine adequate root penetration into both members as to the established design.

8.2 Plates and pressed parts

Before assembly, the pressure parts of the cylinders shall be visually examined for cracks, seams, laminations, galling and freedom from any defects that may ultimately affect cylinder integrity.

8.3 Welded joints

8.3.1 The welding of two-piece cylinder circumferential joints or three-piece cylinder longitudinal and circumferential joints (pressure envelope) shall be by using a fully mechanized, semi-automatic or automatic process to provide consistent and reproducible weld quality.

8.3.2 The longitudinal joint, of which there shall be no more than one, shall be of the butt-welded type.

8.3.3 Circumferential joints, of which there shall be no more than two, shall be:

— butt welded;

— butt welded with one member offset to form an integral backing strip, i.e. joggled [see Figure 4 a)];

— fillet welded [see Figure 4 b)];

— lap welded [see Figure 4 c)].

Lap-welded joints shall have a minimum overlap of four times the minimum design thickness (*a*).

8.3.4 Before cylinders are closed, longitudinal welds shall be visually examined from both sides in accordance with the requirements of ISO 17637.

Permanent backing strips shall not be used with longitudinal welds.

8.3.5 The fusion of the welded metal with the parent metal (pressure joint) for longitudinal seams, circumferential seams and bosses shall be smooth and free from undercutting or abrupt irregularity. There shall be no cracks, notching or porous patches in the welded surface and/or the surface adjacent to the weld. The welded surface shall be regular and even, without concavity.

8.3.6 Butt welds shall have full penetration. The excess thickness shall be such that the weld integrity is not compromised.

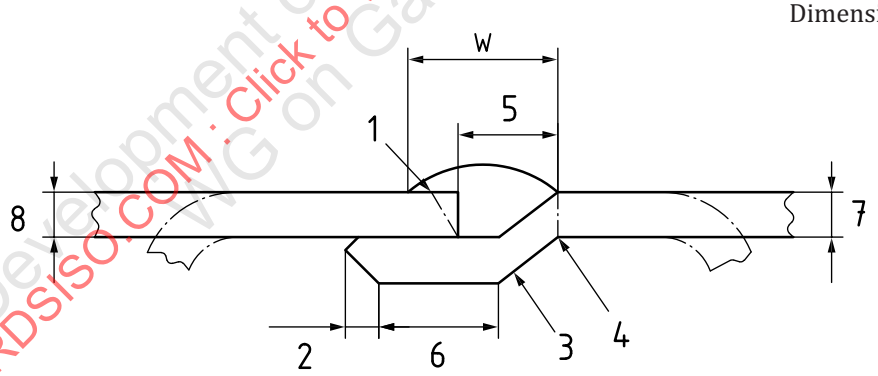
8.3.7 Joggled butt welds shall have adequate penetration verified by bend testing and tensile testing. If adequate material is not available due to the cylinder geometry, the weld shall be verified by macro etch.

8.3.8 Lap welds shall have adequate penetration verified by macro etch and bend testing.

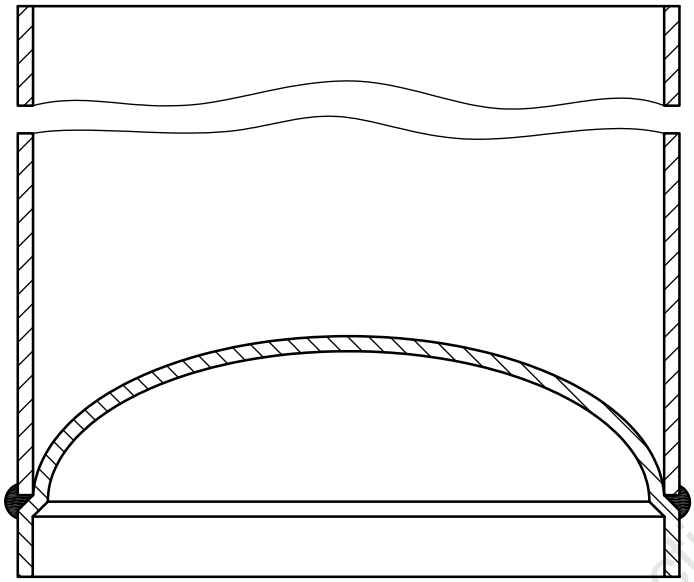
8.3.9 Fillet welds shall exhibit root penetration verified by macro etch.

8.3.10 The fusion of the welded metal with the non-pressure-retaining attachments (e.g. shrouds and footrings) shall be smooth and free from abrupt irregularity. There shall be no cracks, notching or porous patches in the welded surface and/or the surface adjacent to the weld. The welded surface shall be regular and even, without concavity.

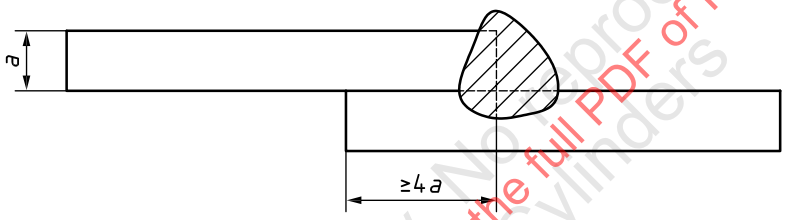
Dimensions in millimetres



a) Joggled butt joint



b) Fillet weld



c) Lap weld

Key

1	bevel (optional)	5	≥ a and ≤ 2,5 a
2	as desired	6	≥ 1,5 a
3	minimum overlap	7	e (thickness of metal which is offset)
4	inside of cylinder, avoid sharp break	8	e_1 (thickness of metal which is not offset)
W	weld width		

Figure 4 — Typical weld configurations

8.4 Tolerances

8.4.1 Out of roundness

The out of roundness of the cylindrical shell shall be limited so that the difference between the maximum and the minimum outside diameters in the same cross-section is not more than:

a) for two-piece cylinders, 1 % of the mean of the diameters;

b) for three-piece cylinders 1,5 % of the mean of the diameters.

8.4.2 Straightness

Unless otherwise shown on the manufacturer's drawing, the maximum deviation of the cylindrical part of the shell from a straight line shall not exceed 0,3 % of the cylindrical length.

8.4.3 Verticality

When the cylinder is standing on its base, the deviation from vertical shall not exceed 1 % including the shroud and footring.

8.5 Non-pressure-containing attachments

8.5.1 Where non-pressure-containing attachments are to be attached to the cylinder by welding, such attachments shall be made of compatible weldable steel.

8.5.2 Attachments shall be designed to permit inspection of welds, which shall be clear of longitudinal and circumferential joints, and so designed as to avoid trapping water.

8.5.3 Where a footring is fitted, it shall be of adequate strength to provide stability and be attached so that it does not prevent inspection of any pressure-containing welds.

All footrings shall be designed to permit drainage and ventilation.

8.5.4 Depending on the geometry of the pressure drum and the surrounding conditions, a pressure drum with a water capacity greater than 150 l shall require specific mechanical or other handling and transportation equipment (e.g. a forklift truck).

The cylinder itself shall have a suitable provision for such a lift to be made (e.g. lugs welded onto the top dome area of the cylinder and/or slots underneath the cylinder) where the forks of a forklift truck can be engaged.

8.6 Valve protection

If a shroud is used to protect the valve, the cylinder containing the shroud shall be drop tested at ambient temperature in accordance with ISO 11117.

8.7 Closure of openings

Apertures in finished cylinders shall be either:

a) fitted with a plug of suitable non-absorbent material; or

b) fitted with the appropriate valve in the closed position or fitting to protect the thread from damage and to prevent entry of moisture into the cylinder.

8.8 Heat treatment

8.8.1 Cylinders shall be delivered in the heat-treated condition for normalizing, stress relieving and stabilizing.

8.8.2 The cylinder manufacturer shall maintain records to indicate that the cylinders have been heat-treated after completion of all welding and to indicate the adequacy of the heat-treatment process used.

8.8.3 Localized heat treatment shall not be used.

9 Testing

9.1 Mechanical testing

9.1.1 General requirements

9.1.1.1 Where not covered by the requirements of this clause, mechanical tests shall be carried out:

a) for the parent material in accordance with ISO 6892-1 for the tensile test;

b) for welded test specimens, in accordance with 9.1.2.

9.1.1.2 All the mechanical tests for checking the properties of the parent metal and welds of the pressure containing shells of the gas cylinder shall be on test specimens taken from heat-treated cylinders.

9.1.2 Types of test and evaluation of test results

9.1.2.1 Sample cylinder tests

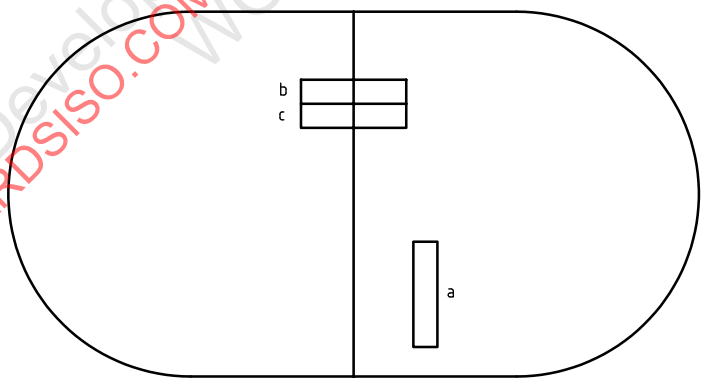
Sample cylinder tests are be carried out as follows:

a) for cylinders containing only circumferential welds (two-piece cylinders), on test specimens taken from the locations shown in Figure 5, the following tests shall be carried out:

   1) one tensile test (in accordance with the requirements of ISO 6892-1), parent metal parallel to the circumferential seam or if it is not possible, in the longitudinal direction, or the centre of one dished end;

   2) one tensile test (in accordance with the requirements of ISO 4136), perpendicular to the circumferential weld;

   3) one root bend test (in accordance with the requirements of ISO 7438), of the circumferential weld;



Key

a Location of test specimen for tensile test.

b Test specimen for tensile test.

c Test specimen for root bend test.

Figure 5 — Test specimens taken from two-piece cylinders

b) for cylinders with longitudinal and circumferential welds (three-piece cylinders), on test specimens taken from the locations shown in Figure 6, the following tests shall be carried out:

1) one tensile test (in accordance with the requirements of ISO 6892-1), parent metal parallel to the circumferential seam or if it is not possible, in the longitudinal direction, or the centre of one dished end;

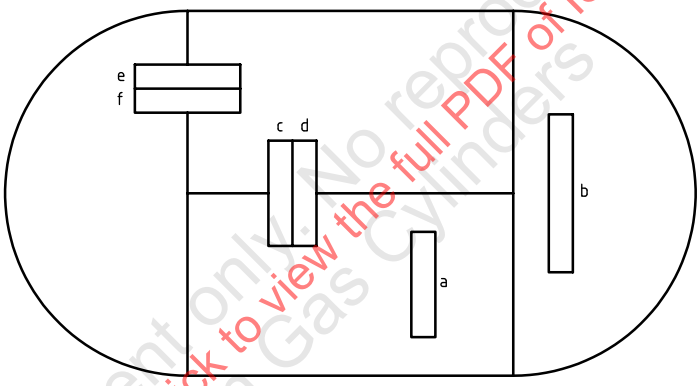
2) one tensile test (in accordance with the requirements of ISO 6892-1), parent metal from one dished end, see Figure 6 b);

3) one tensile test (in accordance with the requirements of ISO 4136), of the longitudinal weld, see Figure 6 c);

4) one root bend test (in accordance with the requirements of ISO 7438), of the longitudinal weld, see Figure 6 d);

5) one tensile test (in accordance with the requirements of ISO 4136), of the circumferential weld, see Figure 6 e);

6) one root bend test (in accordance with the requirements of ISO 7438), of the circumferential weld, see Figure 6 f).



Key

a Location of test specimen for tensile test.
b Test specimen for tensile test.
c Test specimen for tensile test.
d Test specimen for root bend test.
e Test specimen for tensile test.
f Test specimen for root bend test.

Figure 6 — Test specimens taken from three-piece cylinders

9.1.2.2 Tensile test

9.1.2.2.1 Tensile test on parent metal

9.1.2.2.1.1 Tensile tests shall be carried out in accordance with the requirements of ISO 6892-1.

The two faces of the test specimen representing the inside and outside walls of the cylinder, respectively, shall not be machined.

9.1.2.2.1.2 The values obtained for yield stress (R_e) and tensile strength (R_m) shall be not less than those guaranteed by the cylinder manufacturer. Elongation (%) shall not be less than that specified in Table 4.

NOTE $a \leq 3$ for a 20 mm × 80 mm specimen.

$a > 3$, proportional $L_o = 5{,}65\sqrt{S_o}$ specimen.

Table 4 — Elongation requirements

	Minimum elongation after fracture A		
Wall thickness of cylinder shell a mm	$R_m \leq 410$ MPa %	$R_m > 410 \leq 520$ MPa %	$R_m > 520$ MPa %
$a > 3$	29	25	20
$a \leq 3$	22	19	15

9.1.2.2.2 Weld tensile tests

9.1.2.2.2.1 The tensile test perpendicular to the weld (see ISO 4136) shall be carried out on a test specimen having a reduced cross-section 25 mm in width for a length extending up to 15 mm beyond the edges of the weld (see Figure 7). Beyond this central part, the width of the test specimen shall increase progressively.

Dimensions in millimetres

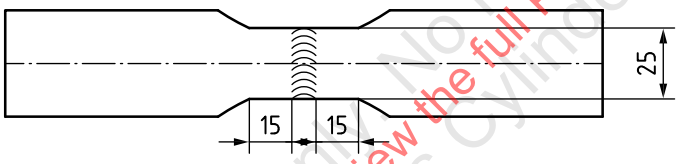
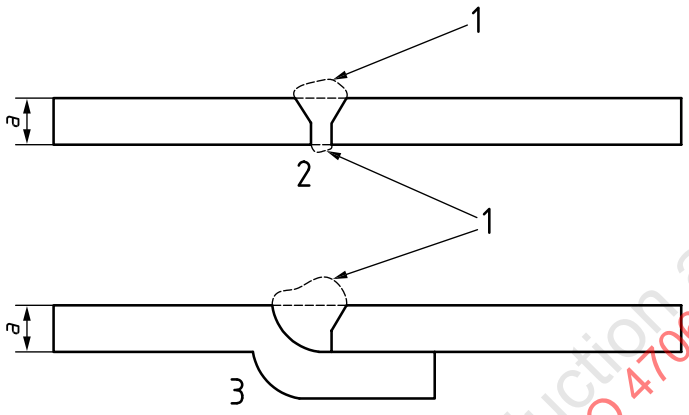


Figure 7 — Test specimen for tensile test perpendicular to the weld

9.1.2.2.2.2 Only the tensile strength (R_m) value shall be determined. The tensile strength value obtained, R_m, shall be not less than that guaranteed by the cylinder manufacturer, R_{mg}, irrespective of where the fracture occurs in the cross-section of the central part of the test specimen.

9.1.2.3 Bend test

9.1.2.3.1 The procedure for carrying out a bend test is given in ISO 7438. The bend test specimen shall be 25 mm in width. The mandrel shall be placed in the centre of the weld while the test is being performed and remain in that position until the conclusion of the test (see Figure 8).



Key

1 weld dressed flush
2 butt weld specimen
3 joggled joint weld specimen

Figure 8 — Typical bend tests

9.1.2.3.2 Cracks shall not appear in the test specimen when it is bent around a mandrel through 180° (see Figure 9).

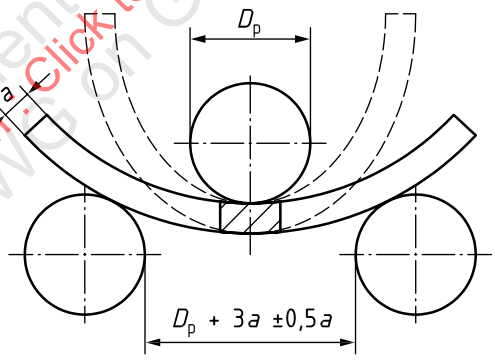


Figure 9 — Typical illustration of bend test

9.1.2.3.3 The ratio n between the diameter of the mandrel D_p and the thickness of the test specimen a shall not exceed the values specified in Table 5.

Table 5 — Ratio of mandrel diameter and test piece thickness

Actual measured tensile strength R_m MPa	n
< 410	2
410 to 520	3
> 520	4

9.2 Burst test under hydraulic pressure

9.2.1 Test conditions

9.2.1.1 If it is proposed to apply markings (in accordance with Clause 14) on the section of the cylinder subjected to pressure, then cylinders to be tested shall be similarly marked.

9.2.1.2 The burst test under hydraulic pressure shall be carried out with equipment that enables the pressure to be increased gradually until the cylinder bursts. The burst pressure (P_b) shall be recorded. The rate of pumping shall not exceed five times the water capacity of the cylinder per hour.

9.2.2 Interpretation of test

The criteria adopted for the interpretation of the burst test are:

a) volumetric expansion of the cylinder that equals:

   1) the volume of water used between the time when the pressure starts to rise and at the time of bursting; or

   2) the difference between the volume of the cylinder at the beginning and the end of the test (see 9.2.3);

b) examination of the tear and the shape of its edges shall be in accordance with 9.2.3.1.

The measured bursting pressure, P_b, shall not under any circumstances be less than double the pressure P_h and not less than 50 bar.

9.2.3 Volumetric expansion

The ratio of volumetric expansion of the cylinder at burst to its initial volume shall be greater than or equal to:

a) where the minimum value of R_{mg} is ≤ 410 MPa:

   1) 20 % if the length of the cylinder is greater than its diameter;

   2) 14 % if the length of the cylinder is equal to or less than its diameter;

b) where the minimum value of R_{mg} is > 410 MPa:

   1) 15 % if the length of the cylinder is greater than its diameter;

   2) 10 % if the length of the cylinder is equal to or less than its diameter.

9.2.3.1 Type of fracture

The following requirements apply:

a) the burst test shall not cause any fragmentation of the cylinder;

b) the main fracture shall not show any brittleness (i.e. the edges of the fracture shall not be radial but shall be at an angle to a diametrical plane and display a reduction of area throughout their thickness);

c) the fracture shall not reveal a visible defect in the metal;

d) the fracture shall not initiate in a weld;

e) the fracture shall not initiate in a marking area (see 14.3);

f) the fracture shall not initiate from a weld securing a footring or shroud.

9.3 Pressure test

9.3.1 The pressurization medium may be liquid or gas provided safety precautions have been taken.

9.3.2 The pressure indicating device(s) shall be certified to an accuracy of 0,5 % at cylinder test pressure (P_h).

9.3.3 The manufacturer shall employ manufacturing practices and techniques that will demonstrate that the cylinders do not leak when subjected to the minimum test pressure (P_h).

9.3.4 The minimum test pressure P_h to be applied shall be as specified in 6.1.3.

For butane only, the stress within the wall of the cylinder shall not exceed 90 % of the minimum yield strength of the material i.e. R_{eg} during the test.

9.3.5 The pressure in the cylinder shall increase gradually until the test pressure is reached.

9.3.6 The cylinder shall remain at the test pressure for a period of time, at least 10 s for testing with gaseous media and 30 s for liquid media, that will make it possible to establish that no leak in the cylinder or welds can be observed.

9.3.7 After the test, the cylinder shall show no signs of permanent deformation.

9.3.8 Where the manufacturer employs a gas as the pressurization medium for the pressure test, then no leakage test shall be required. Otherwise, each cylinder shall be subjected to a leak test using a gaseous media at the marked service pressure of the cylinder.

9.4 Radiographic and macro examination

9.4.1 Radiographic examination

9.4.1.1 General

The radiographic examination may be replaced by radioscopy or another suitable non-destructive testing method if the applied method is carried out in accordance with a process that provides the same level of quality of examination as radiographic examination. Radiographic examination shall conform to the techniques specified in 9.4.1.4 and 9.4.1.5. Radiographic examination of the circumferential seam on two-piece cylinder designs is not required.

9.4.1.2 Joint efficiency "J" shall be 1,0 when each of the total circumferential seams and longitudinal seam is radiographed completely.

9.4.1.3 Joint efficiency "J" shall be 0,90 when 1 cylinder from each batch of 250 consecutively welded cylinders is spot radiographed. In addition, 1 cylinder out of the first 5 cylinders welded following a shutdown of welding operations exceeding four hours shall be spot radiographed. Spot radiographs shall be made of a finished welded cylinder and shall include both "T" intersections girth weld for 50 mm in both directions from the intersection of the longitudinal and circumferential welds and include at least 150 mm of the longitudinal weld.

9.4.1.4 Welds shall be radiographed in accordance with ISO 17636-1 or ISO 17636-2, Class B.

9.4.1.5 Cylinders shall not have any of the following imperfections as specified in ISO 5817, Class B:

a) cracks, inadequate welds, lack of penetration or lack of fusion of the weld;

b) elongated inclusions or any group of rounded inclusions in a row where the length represented over a weld length of 12a is greater than 6 mm;

c) any gas pores measuring more than (a/3) mm;

d) any gas pores measuring more than (a/4) mm, which is 25 mm or less from any other gas pore;

e) gas pores over any 100 mm length, where the total area, in mm^2, of all the figures is greater than 2a.

9.4.2 Macro examination

The macro examination, carried out in accordance with ISO 17639, of a full transverse section of the welds shall show complete fusion and complete penetration as specified in 8.1.9 d). In case of doubt, a microscopic examination shall be made of the suspect area.

9.4.3 Examination of flange welding

For the examination of the boss welding, a radiographic or macro examination shall be carried out at time of type approval as indicated in 11.1 or at any time the welding parameters change.

9.4.4 Examination of welding of non-pressure containing attachments

For the examination of welding of non-pressure containing attachments, radiographic or macro examinations shall be carried out at the time of type approval in accordance with 11.1 or at any time the welding parameters change.

9.4.5 Unacceptable imperfections at radiographic or macro examination

If the spot radiographic examination fails to meet the requirements of this document, two additional cylinders from the same lot of 250 cylinders or less shall be examined. If either of these fails to meet the requirements, production shall be stopped, and every cylinder welded since the preceding acceptable radiographic shall be set aside and each cylinder shall be examined by spot X-ray. Only those cylinders passing are acceptable. Production shall not be restarted until the cause of the defect has been established and rectified, and the starting up test procedure as specified in 10.1.3 has been repeated.

If any of the macro examinations show any unacceptable imperfections, production shall be stopped, and every cylinder welded since the preceding acceptable macro examination shall be set aside until it is demonstrated that these cylinders are satisfactory either by radiographic or macro examination or other appropriate means. Production shall not be restarted until the cause of the defect has been established and rectified, and the starting up test procedure as specified in 10.1.3 has been repeated.

9.5 Visual examination of the surface of the weld

9.5.1 Examination of the completed weld in accordance with the requirements of ISO 17637 shall be carried out when the weld has been completed. The welded surface examined shall be well illuminated, and shall be free from grease, dust, scale residue or protective coating of any kind.

9.5.2 The weld shall conform to the requirements of 8.3.

10 Acceptance criteria

10.1 All acceptance testing as required by this clause shall be carried out on cylinder shells, prior to surface treatment.

10.2 All cylinders shall be subject to a pressure test as specified in 9.3 and visual examination of the surface of the welds as specified in 9.5.

10.3 Radiographic examination and macro examination shall be carried out as specified in 9.4. Radiography shall be carried out on the longitudinal weld (see Figure 10) of the first production cylinder or of an inspection lot after a change in type or size of cylinder or the welding procedure (including machine setting), or after a break in production exceeding 4 h.

In the case of cylinders with an outside diameter less than 250 mm, radiography of the longitudinal joints welds may be replaced by two macro examinations (see 9.4.2), one of which shall be at the plane of the stop/start area and the other on the opposite side of the cylinder.

For cylinders with longitudinal welds, 1 cylinder out of every 250 production cylinders shall have the junction of the longitudinal and circumferential welds radiographed as indicated in Figure 10.

Where more than one welding machine is used for production, the above procedures shall apply to each machine.

Dimensions in millimetres

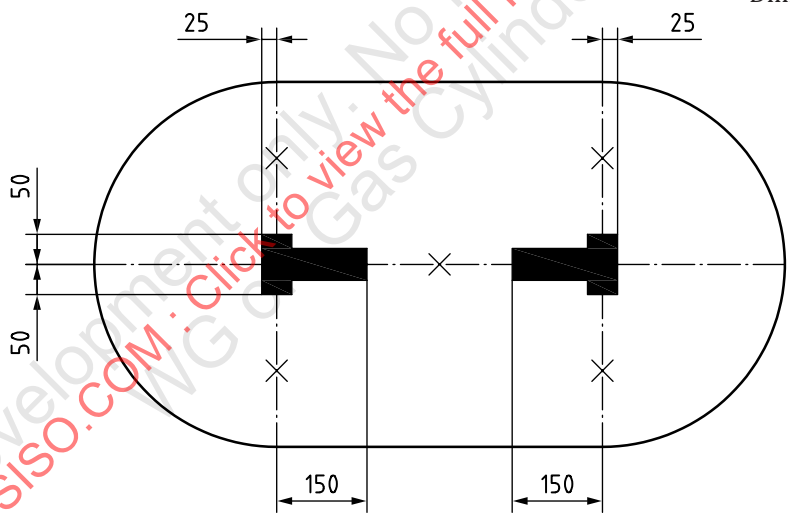


Figure 10 — Extent of radiography of welds (black sections in the figure) — Cylinders with circumferential and longitudinal welds

10.4 Mechanical testing as specified in 9.1 and burst testing as specified in 9.2 shall be carried out on samples as specified in 12.1.

10.5 The cylinder used for mechanical testing shall be profiled for determination of the minimum wall thickness. The minimum wall thickness noted in the cylinder sidewall shall be ≥ a and the minimum wall thickness in the cylinder heads shall be ≥ b.

11 Type approval

11.1 The manufacturer shall make available a batch of at least 30 finished cylinders marked using production equipment, from which the inspector shall select cylinders for:

a) pressure cycling test testing as specified in 11.3, three cylinders;

b) mechanical tests as specified in 9.1, two cylinders;

c) radioscopy/macro examination as specified in 9.4; (macros may be removed from cylinder used for mechanical tests), two cylinders;

d) burst test as specified in 9.2, two cylinders;

e) cylinder wall thickness profile as specified in 10.1.5, two cylinders.

If the results of the tests are satisfactory, the inspector shall issue a new design type approval certificate, a typical example of which is given in Annex A.

11.2 A cylinder shall be considered a new design, compared with an existing approved design, when:

a) it is manufactured in a different factory;

b) it is manufactured by a different process;

c) it is manufactured from a different specified chemical composition range (e.g. 0,06 carbon versus 0,18 carbon) as specified in 5.2;

d) it is given a different heat treatment (normalizing, stress relieving, stabilizing);

e) the design profile of the base has changed;

f) the weld-joint design has changed;

g) the number of openings has increased;

h) the inside diameter of an opening (pierced/punched hole in cylinder head) has increased by 100 % or more;

i) the test pressure has increased by more than 2 bar;

j) the minimum design wall thickness or design diameter is changed by 10 % or more; or

k) the end thickness or water capacity has changed by more than 30 %.

11.3 Fatigue testing/cycle testing

11.3.1 For the purpose of this test, three cylinders which are guaranteed by the manufacturer to be representative of the minimum end(s) thickness set by the design and which include all markings (in accordance with Clause 14) shall be filled with a non-corrosive liquid and subjected to successive reversals of hydraulic pressure.

11.3.2 The test shall be carried out at an upper cyclic pressure, either:

a) equal to two thirds of the test pressure, in which case the cylinder shall be subjected to 80 000 cycles without failure; or

b) equal to the test pressure, in which case the cylinder shall be subjected to 12 000 cycles without failure.

11.3.3 The value of the lower cyclic pressure shall not exceed 10 % of the upper cyclic pressure. The frequency of reversals of pressure shall not exceed 0,25 Hz (15 cycles/min). The temperature measured on the outside surface of the cylinder shall not exceed 50 °C during the test.

11.3.4 After testing in accordance with 11.3, the cylinder shall be burst tested. When burst tested, the cylinder shall conform to the requirements of 9.2.

12 Batch tests

12.1 Inspection lots

For acceptance purposes, the batch shall be divided into inspection lots not exceeding 1 000 cylinders. For selection of sample cylinders for either burst or mechanical tests, each lot is subdivided into sub-lots of 250 cylinders during the first 3 000 cylinders of a batch and thereafter sub-lots of 500 or 1 000 cylinders, depending on cylinder size (see Figure 11).

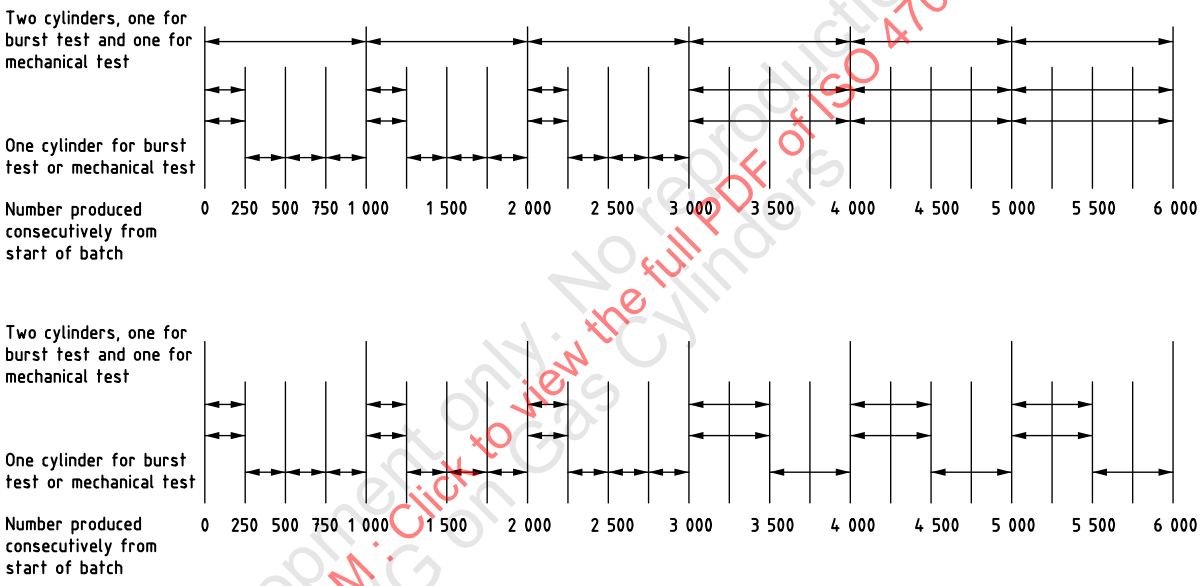


Figure 11 — Inspection lots

12.2 Rate of sampling

12.2.1 Where a batch contains more than one cast, the manufacturer shall arrange for samples tested to represent each cast of material used.

NOTE The reduced rate of sampling for large volume manufacture (above 3 000 cylinders) is usually subject to written agreement with an inspector once the manufacturer can demonstrate that the batch production test results and manufacturing processes are consistently reliable without any major interruption of manufacture.

12.2.2 From the first 250 cylinders or less in each inspection lot, representative cylinders shall be taken at random, one for the mechanical tests (see 9.1) and one for the burst test (see 9.2). Cylinders which have a water capacity less than 6,5 l and a burst pressure greater than 100 bar, shall be either burst tested or mechanically tested.

12.2.3 From each subsequent group of 250 cylinders or less in the inspection lot, one representative cylinder shall be taken at random for either a burst test or mechanical tests.

12.2.4 Radiographic examination, where required, shall be at the frequency specified in 10.1.3.

12.3 Quantity ≤ 3 000 cylinders water capacity less than or equal to 35 l

12.3.1 For cylinders with a water capacity less than or equal to 35 l, for the first 3 000 cylinders in the batch, representative cylinders shall be taken as specified in 12.2.2, 12.2.3 and 12.2.4.

12.3.2 From each inspection lot over 3 000, representative cylinders shall be taken at random, one for the burst test and one for mechanical tests for each 1 000 manufactured (see Figure 11).

12.4 Quantity over 3 001 cylinders water capacity greater than 35 l

12.4.1 For cylinders with a water capacity greater than 35 l, for the first 3 000 cylinders in the batch, representative cylinders shall be taken as specified in 12.2.2, 12.2.3 and 12.2.4.

12.4.2 From each inspection lot over 3 001, representative cylinders shall be taken at random. From the first 500 cylinders or less in each inspection lot remaining, representative cylinders shall be taken at random, one for the burst test and one for mechanical tests. From the remaining 500 cylinders or less in such inspection lots, one representative cylinder shall be taken at random for either a burst test or mechanical tests (see Figure 11).

12.5 Failure to meet batch test requirements

12.5.1 In the event of failure to meet batch test requirements, retesting shall be conducted.

12.5.2 If there is evidence of a fault in carrying out the mechanical tests, or of an error of measurement, a second test on the same cylinder shall be performed. If the result of this test is satisfactory, the first test shall be ignored.

12.5.3 Retest specified in 12.5 shall be in accordance with 12.2. 2, 12.2.3 and 12.2.4.

12.5.3.1 If a single cylinder fails the initial mechanical or burst test, cylinders shall be taken at random from the same sub-lot, in accordance with Table 6, and shall be retested for both mechanical and burst tests.

Table 6 — Batch retest requirements

Inspection sub-lot size	Failure	Retest
≤ 250	1M	2M + 1B
≤ 250	1B	2B + 1M
> 250	1M	2M + 2B
> 250	1B	1M + 4B
Key M = mechanical test B = burst test		

12.5.3.2 In the event of more than one cylinder failing the initial tests or one or more cylinders failing the retest specified in 12.5, the batch shall be rejected. If the manufacturer reheat treats the rejected batch or repairs any weld defects and reheat treats the batch, then the batch shall be resubmitted as a new batch as specified in 12.2.2, 12.2.3 and 12.2.4.